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INTEGRATE, TEST AND QUALIFY NASA FACILITY CLASS PAYLOADS ON THE ISS JEM-EF

Langford, D. E. (1), Croonquist, A. P. (1), Taylor, M. D. (1), Liu, F. C. (1), Mitchell, M. A. (2)
(1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109,
(2) Teledyne Brown Engineering, Inc., 300 Sparkman Dr., Huntsville, AL 35805
dlangfor@squid.jpl.nasa.gov

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(1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, (2) Teledyne Brown Engineering, Inc., 300 Sparkman Dr., Huntsville, AL 35805
dlangfor@squid.jpl.nasa.gov

Abstract-- There are similarities in the physical activities and in the documentation that is developed by the ISS Payloads Office and the Payload Developer (PD) to what the Shuttle Mission Manager and Shuttle Experiment Project teams performed to successfully fly experiments on the Shuttle. Because the ISS uses many more systems and operates many payloads there are additional tasks that PDs must accomplish to get approval to fly on the ISS using the STS. For NASA payloads that are attached to the JEM-EF there are additional tasks that the PDs and NASA's Payloads Office must accomplish to satisfy the requirements of NASDA. This paper describes the processes that the Low Temperature Microgravity Physics Facility (LTMPF) follows or will follow to meet the qualification requirements imposed by the Jet Propulsion Laboratory (JPL), by the Microgravity Research Program Office (MRPO) at MSFC, by the ISS Payloads Office (OZ) at JSC, and by NASDA's JEM Element Integration Office. The integration of the LTMPF payload, its instruments and the verification of the interfaces (mechanical, thermal, power, telemetry, and command) with a shuttle cargo bay carrier and JEM-EF is an integral part of the qualification process and will be developed in this paper. The ISS Payloads Office and NASDA provide ISS simulators that PDs can use at their development site or at the launch site; but there are no actual ISS subsystems to mate with to ensure compatibility. This paper will provide a PD's view of the process, establish the flow or timeline in relation to the payload development schedule and discuss the relationships with the ISS Payloads Office, the Research Program Office, the launch site Integration Office and NASDA for the LTMPF payload.

Introduction

NASA and its Prime Contractor Boeing are responsible for the integration and verification of the ISS. This includes end-to-end verification of the physical, functional, safety, and operational requirements for the entire system, including payloads. The paper[1] by Kathryn Clark, Ph.D., "NASA's Attached Payload Utilization Plans" is an excellent overview of NASA's utilization plans for attached (external) payloads on the International Space Station (ISS).

The integration of the LTMPF payload, its instruments and the verification of the mechanical, thermal, power, telemetry, and command interfaces with the ISS is an integral part of the qualification process and will be developed in this paper. This integration process starts at JPL and is completed at the launch site where the payload will be launched on a crossbay carrier in the shuttle following a successful Certification of Flight Readiness (CoFR) Review. The LTMPF is compatible with NASDA's H-IIA expendable rocket for future missions. The first actual (live) checkout of ISS payloads with the Station will be after the payload is installed in the ISS or attached to an exposed attachment site. The ISS Payloads Office provides a portable ISS simulator called a Suitcase Test Environment for Payloads (STEP)

that payloads can use at their development site. For ISS interface verification at KSC the Payload Test and Checkout System (PTCS) is used; the PTCS can be connected to either ISS Racks or attached payloads. In addition to the PTCS there is a Payload Rack Checkout Unit (PRCU) that provides power characterization for margin testing. The NASA locations with a PRCU are JSC, MSFC, GRC and KSC. Most payloads developed at locations with access to just a STEP will need to use both the PRCU and the PTCS for power and communication interface compatibility with the ISS power, 1553B, Ethernet, or High-rate fiber interfaces. This paper will provide a payload's view of the process, establish the flow or timeline in relation to the payload development schedule and discuss the relationships with the ISS Payloads Office, the Research Program Office, the launch site Integration Office and NASDA for the LTMPF payload.

Verification Planning

The ISS Payloads Office[2] has developed a process to plan and execute verification that payloads meet the ISS requirements. At the heart of the process is the verification logic network that defines the closure strategy for each requirement. Once every detailed verification objective in a single verification logic network has been satisfied, the corresponding requirement has been satisfied. The analysis flows that the Payload Hardware and Software Engineering Integration (PEI) team uses are contained in SSP 57011. Final verification submittals are required by at L-7.5 months.

One of four verification methods - test, demonstration, analysis, or inspection - will be used to satisfy each detailed verification objective. Testing is the desirable method of verification.

Each element or payload and its components will go through a rigorous qualification and acceptance test program to certify the design and demonstrate the component/flight element will function properly within the environmental conditions which it will see over its mission (launch/return and on orbit).

Robotic verification will be performed to determine the operational kinematics and dynamic capabilities of the Shuttle remote manipulator system (SRMS) and the Space Station remote manipulator system (SSRMS) such that reach, access, and robotic interfaces will permit the accomplishment of robotic assembly tasks. It will also verify operator-in-the-loop requirements for adequate visual cues through direct views, indirect camera views, and the use of artificial vision systems. SSRMS task verification will be performed using computer-simulated SSRMS activities. With few exceptions, all attached payloads will be attached to sites at the Columbus Module, the Station truss, or Japanese Experiment Module using Extravehicular Robotics (EVR) versus Extravehicular Activity (EVA) to limit the required crew operations. Payloads will benefit through reduced training and greatly simplified trainers or full-scale mockups to be used to verify the transfer procedures and locations of handling interfaces.

Payload Verification and Launch Site Support

The Payload Verification and Launch Site Processing Team (PVLSPT) is responsible for implementation of the Program's payload verification policies, processes and requirements and for managing Program resources provided at the launch site (i.e., KSC) for payload processing. The team develops the payload verification program policy and the verification requirements associated with payload-to-station and payload-to-carrier interfaces and design-to requirements. The PVLSPT manages the scheduling of the Suitcase Test Environment for Payloads (STEP) and Payload Rack Checkout Unit (PRCU) distributed test tools to payload developers.

The processes and policies related to performing Payload Verification are defined in the Payload Verification Program Policy (PVPP) and in SPIP Volume IV, Payload Integration. The process for performing Launch Site Processing is defined in SPIP Volume VI, Launch Site Processing.

Payload Process

With the transition to ISO certification by NASA and its industrial partners the payload development through mission operations phases are driven by well defined processes controlled by each NASA Center or the industrial partners. NASA also uses Intercenter Agreements and Memorandum of Agreement (MOA) for Safety and Mission Assurance to give each payload developer at a NASA Center control over qualification and verification. Exceptions to this are analysis or testing that the PVLSPT or the equivalent team from ESA or NASDA must perform to ensure payloads are compatible with each other and with the ISS payload sites; and that all payloads together do not over-subscribe the available ISS power, telemetry or commanding resources.

For the Jet Propulsion Laboratory (JPL), the integration, test and qualification of NASA Facility Class Payloads[3] is controlled by JPL's "Integrate and Test Mission Systems" process. This process requires that all projects shall have a written Flight System Integration and Test Plan covering all system integration and test activities, system delivery, installation, launch, and hand-off to Mission Operations with provisions for reporting on those activities.

The Flight System Integration and Test Plan shall

- Show requirements traceability from project-defined system requirements to test procedures;
- Specify Mission Assurance, Product Assurance, and Quality Assurance as required in the Project Implementation Plan (PIP) and the Safety & Mission Assurance Plan (S&MAP);
- Identify written procedures to support the Flight System Integration and Test Plan;
- Specify safety and security requirements as identified by the Project S&MAP;
- Specify requirements for documentation and recording of test status and test results in the form and format required by the Project PIP;
- Specify the conduct of personnel operating support equipment within the requirements of the S&MAP;
- Specify requirements for packing, storing, shipping and/or delivering, installing and handling of flight and ground products as defined by the Project Implementation Plan;
- Specify control and disposition of non-conforming products, test equipment and support technology.

Assembly Test and Launch Operations (ATLO) Procedures shall be written to cover all requirements specified in the Flight System Integration and Test Plan. The ATLO Procedures shall include:

- Standards for test procedures specified by the Project Safety and Mission Assurance Program Plan for flight, ground and data system I&T;
- Procedures for the validation and installation of software for both flight and ground elements;
- Facility operations procedures generated and provided by the facility managers or the responsible organization;
- Where appropriate, the project's ATLO Procedures shall be reviewed for compliance with JPL policies for safety of flight hardware and personnel;
- Operations Safety Surveys and Facility Safety Surveys shall be conducted jointly by the Systems Safety Office, the ATLO Manager, and the facility managers prior to operations in each facility.

Flight Hardware, Flight Software, and Electrical Ground Support Equipment shall be certified prior to use to a standard determined by the Project Safety and Mission Assurance Plan:

- Mechanical Ground Support Equipment including lifting equipment and handling equipment shall be certified for use with flight hardware to appropriate standards as determined by the Project Safety and Assurance Plan and the policies of the Office of Safety and Mission Success;
- Procedures for performing requirements and design verification and validation shall be documented and based on Verify, Integrate, Validate, and Operate (VIVO) Process Model Verification & Validation techniques.

A project shall have written procedures covering all operations at the launch facilities. The procedures shall be compliant with the Launch Operations Procedures specified by the ATLO Plan and/or by the launch facility.

- The Flight System Integration and Test Plan shall specify the training required to ensure the readiness of integration and test personnel to support the mission.
- Specific training and certification as required for test facility operations and operators shall be performed by the organization responsible for the facility.
- Training for operation at the Eastern Test Range will be specified and conducted per JPL and launch site operations requirements.
- JPL requirements for property control and shipping as specified by Office of Safety and Mission Success (OSMS) and Business Operations will be observed.
- Certified carriers as specified by OSMS and the Project Safety and Mission Assurance Plan will perform transportation of flight hardware.
- Instrumentation and test equipment shall be calibrated and maintained in accordance with OSMS Policy and the Test and Calibration Process.

A project shall have a written Mission Operations Plan to be used by the operations organization to conduct mission operations that shall be based on the Project Implementation Plan, Project Safety and Mission Assurance Plan, and, where applicable, shall:

- Include the policies, plans and requirements to be used by the operations organization to conduct mission operations based on the Mission Requirements, Project/ Experiments Plans;
- Contain provisions for documenting operations support provided by other organizations to the Project;
- Include Safety and Security requirements and plans in accordance with the Safety and Mission Assurance Program Plan for operations and operations personnel;
- Include, as applicable, a data user support plan based at least on the Project Implementation Plan, Science Requirements, Experiments User Guides, and system design;
- Include plans for the distribution and archiving of data to be provided to the science community throughout the life of the mission as specified in the Archiving Plan;
- Document the process for authorization of commands to be transmitted to the flight element;
- Include contingency plans for the resolution of in-flight anomalies of the payload and experiments;
- Specify and conduct the training required to ensure the readiness of Operations personnel to support the mission.
- Include applicable ISS Driven Policies.

The project shall have a Flight Rules and Constraints Document that contains a set of in-flight limitations and restrictions on the operation of the payload.

Payload Qualification and Verification

Payloads such as the LTMPF payload must define and document the set of verification

activities necessary to ensure compliance with the requirements identified in the Interface Requirements Documents for the JEM-EF, Shuttle/Cargo Bay Carrier, and/or H2-A/HTV Carrier. NASA attached payloads for Truss attachment sites have baselined documentation and blank books available in PALS to guide the development of Unique Payload Verification Plans (UPVP), Payload Integration Agreements (PIA), Hardware and Software Interface Control Documents (ICD) and Interface Requirements Documents (IRD). In addition the verification of functional and safety requirements are documented in System Test and Launch Operations Plans such as JPL's ATLO plans for each flight project. The LTMPF project shall consult NSTS 1700.7 ISS Addendum to understand both the generic and unique payload safety requirements.

The LTMPF project has followed the baselined NASA documentation for ISS payloads to develop its requirements documents, plans, and agreements; and at the same time interfaced with its NASDA counterparts to gain insight into what NASDA will require for NASA payloads manifested to be attached to the JEM-EF facility. NASDA and ESA are actively developing the processes and documents that payloads will follow for their payload sites using the NASA documents; they are using the first NASA payloads manifested for their attachment sites to co-develop bilateral guidelines and agreements. The International Partner agreements with NASA play into the process and payloads such as LTMPF rely on ISS's Payloads Office (OZ) to orchestrate this dynamic evolution. For the early payloads on the JEM-EF, such as LTMPF there will be re-writes of the UPVP and the PIA after NASA and NASDA determine what ISS documentation NASA payloads on JEM-EF should use as guides, and which payload developed documents will be required.

Documentation Tree for JEM-EF Payload Integration

SPIP Vol. 1 Program Management Plans – SSP50200V1
SPIP Vol. 4 Payload Engineering Integration – SSP50200V4
SSP 57011: Payload Verification Program Plan (PVPP)

1. Payload Integration Agreements

SSP 57061: Standard Payload Integration Agreement for Unpressurized Payloads (SPIA) with
Payload Unique Integration Agreements
SSP 57062: PIA Increment Addendum for Unpressurized Payloads with
Payload Unique PIA Increment Addendum
SSP 52000-PDS: Payload Data Sets Blank Book with
Payload Unique Data Sets

2. Payload Interface Requirements and Verification Documents

NASDA-ESPC-2900 : JEM EF/Payload Standard ICD (JPAH Vol. 3)
NASDA-ESPC-2901 : JEM RMS/Payload Standard ICD (JPAH Vol. 4)
NASDA-ESPC-2902 : JEM ELM-ES/Payload Standard ICD (JPAH Vol. 5)
NASDA-ESPC-2903 : JEM Airlock/Payload Standard ICD (JPAH Vol. 6)
NASDA-ESPC-2567 - Communication Protocol and C&DH Service Std. ICD (JPAH Vol. 7)
Payload Unique Hardware ICDs (bilateral document)
Payload Unique Verification Plan
Payload Unique Verification Reports

3. ISS Payload Accommodations Handbooks

NASDA-ESPC-2897: JEM Payload Accommodations Handbook (Main Volume)

Payload Unique Documents

- Payload Interface Requirements are defined in JPAHs.
- Based on applicable JPAHs, a Payload Unique ICD will be established.
- Payload Unique Verification Matrix is attached in Payload Unique ICD.
- Payload Unique PIA Increment Addendum
- Payload Unique Data Sets
- Standard & Payload Unique documents will be controlled and maintained by NASA (OZ).

NASDA Transition Tasks

Unique ICD Blank Book (JFX-TBD)
Unique ICD Guideline (JFX-2001122)

(These documents are used for reference to establish Payload Unique ICD.)
(These documents in English will be established after Japanese versions are established.)

The verification of payload functional capabilities for achievement of science objectives and/or payload safety hazard controls is not within the scope of this paper. The functional requirements will be addressed in the project's System Test and Launch Operations (ATLO) Plan and the Mission Operations Plan. Likewise the safety requirements verification will be under the direction of the LTMPF Safety Engineer who will use a combination of Intercenter Agreements, JPL's Structures and Materials Safety Review Committee (SAM-RC), and ISS-specific safety verification processes to assemble the Flight and Ground Phase 0/I, II and III Safety Data packages for safety-panel review.

JEM-EF Payload Verification Requirements (JPAH Vol. 3)

- Because NASA decided to abolish "Generic Payload Verification Plan (SSP 57010/57013)", NASDA also decided not to establish verification require documents for JEM-EF payloads. (NASDA thinks it is possible to be covered through Unique PIA & Unique ICD coordination.)
- Each JPAH contains standard Payload Verification Matrix.
- PD shall submit payload unique verification plan in accordance with verification matrix defined in Payload Unique ICD to NASA and NASDA (defined in SPIA-SSP57061).
- PD shall submit the verification results for review and approval by NASDA and NASA (defined in SPIA-SSP57061).

PAYLOAD VERIFICATION

A generic set of Verification Definition Sheets (VDS) provides instructions, definitions, references, and guidelines for the verification activities associated with each payload design requirement contained in the IRD. The VDS describes what steps should be taken by the PD to verify that the payload hardware and software has satisfied the specific IRD requirement.

The implementation and reporting phase of the Unique PVP process consists of performing the verification as defined in the VDSs contained in the Unique PVP. This phase also covers verification statusing and tracking; data deliverables and schedules; and support of ISS safety and integration reviews.

The certification process includes the signing by the PD of a statement indicating that all of the requirements and their associated verification for ISS compatibility, functionality and safety compliance have been observed. Refer to SSP 52054, ISS Payloads Certification of Flight Readiness Implementation Plan Generic, for details of the Certification of Flight Readiness (CoFR) process.

Engineering Analytical Integration

Inputs from NASA (OZ)

- Unique PIA
- Unique PIA Increment Addendum
- Unique PDS
- Unique ICD
- PL Mass Models

NASDA PEI Tasks

- Integrated Thermal Analysis
- Integrated Structure Analysis
- Microgravity Analysis
- Contamination Analysis
- EMC Analysis
- Electric Power Stability Analysis
- Other

NASDA PEI Products

- Element-Level Engineering Analysis Reports
  1. JEM System Compatibility (large payload)
     - Mass Properties
     - Stiffness
     - Interface Design Load

- Thermal Environment
- Envelope
- Etc

2. JEM System Environment
   - Contamination Environment
   - μG
   - Etc

B. Operations Guidelines and Constraints

Use

A. ISS level Analysis (per SSP57011 – PVPP)
B. Payload Unique Verification Report

Conclusion

The integration, testing, and qualification of NASA Facility Class Payloads is patterned after the process developed and used for shuttle payloads; developers that have flown payloads in the Shuttle will be familiar with the requirements. The ISS process and requirements are more complex and also require interfacing with the ISS International Partners (IP) for payloads attached to either the NASDA or ESA facilities. The suite of documentation is still evolving (except for the shuttle launch); more so for IP documentation that is developed only after NASA has baselined its version of a document. The Microgravity Research Program Office (MRPO) participates in systems and hardware design reviews, meeting and telephone conferences; evaluating programmatic data for approval and certification; and striving to resolve issues pertaining to the development, integration, manifesting, and transport of external payloads. MRPO often represents the NASA-developed payloads to the ISS Payloads Office (OZ) and Headquarters Code U, and elevates issues to resolution; MRPO is responsible for the Certification of Flight Readiness, and will endorse the Payload CoFR upon fulfillment of all obligations per SSP52054. ISS Payloads Office (OZ), and NASDA have provided much needed guidance for the LTMPF Project during the formulation phase.

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